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United States
Department of
Agriculture

Forest Service

**Intermountain
Forest and Range
Experiment Station
Ogden, UT 84401**

Research Paper
INT-327

March 1984

Tree Diameter Measurements At English and Metric Standard Heights: A Comparison

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RESEARCH SUMMARY

The impact of measuring trees at 1.3 m versus 1.37 m heights above ground line was analyzed. The results indicate that the difference in diameter measurement taken at the two points averages around 1 percent. An equation for converting from English diameter at breast height to the metric equivalent of 1.3 m is presented.

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INTRODUCTION

On December 23, 1975, President Ford signed into law the Metric Conversion Act. The act calls for voluntary conversion; however, foresters who attempt to comply may be faced with some rather difficult decisions on how to conduct their traditional field inventories and data analyses.

The Nationwide Forest Survey is a good example. At present, trees are measured to specified merchantability standards. Should these standards be maintained and "soft" conversion to metrics be accomplished through application of various factors or should the standards be changed to conform to even centimeter/meter classes? Similarly, should volume models based on English units be converted or should new metric models be developed?

Fundamental to many of the questions relating to metric conversion is: Where should diameter at breast height (d.b.h.) be measured? International users of the metric system commonly measure d.b.h. at 1.3 m. Both Australia and Canada, for example, have accepted this point on the stem as their measurement standard. Other countries, such as the United States, have traditionally measured d.b.h. at 4.5 ft. In metric this converts to 1.37 m, 7.2 cm higher on the bole than the metric standard.

In the United States, the Society of American Foresters, working with the American National Metric Council, is proposing that d.b.h. be measured at 1.3 m above ground line (Folliott and others 1982).

Some ongoing inventories are taking measurements in metric units, including diameter at 1.37 m, and then through conversion computing standard reporting units (Oswald 1979). Most, however, are taking measurements in the usual manner and then showing metric equivalents in the reports. Procedures have been developed to convert English diameter measurements to the metric to produce volume estimates in cubic meters. Bruce (1979), for example, gives the following diameter conversion for West Coast Douglas-fir:

$$\text{metric d.b.h.} = 1.00513 \text{ English d.b.h.}$$

Berry (1980) developed another conversion for white spruce:

$$\text{metric d.b.h.} = -0.049 + 1.01 \text{ English d.b.h.}$$

Bruce also cites a New Zealand study that suggests applying the conversion factor 1.0075 to the coefficient for d.b.h. in volume equations based on English measurement.

Meyers and Edminster (1974) present a method for converting from English to metric units volume equations of the form

$$\text{Volume} = a + bD^2H.$$

But there is no mention about the effect of diameter measurement taken by English versus metric standards.

Demaerschalk (1972) also gives procedures for conversion of taper and volume equations from English to metric units. Again, there is no comment about the effects from place of diameter measurement.

In the Rocky Mountains, the English volume equations are in numerous model forms not amenable to simple metric conversion. The most practical approach is to continue taking field measurements in English units, use existing English volume equations, and convert results of the equations to metric units—a soft conversion method. An initial phase in exploring this approach was to determine whether or not there was a significant difference in volume prediction from English equations when using d.b.h. measured at 1.3 m instead of 1.37 m for Rocky Mountain species. If the difference was significant, a correction factor for adjusting 1.37 m d.b.h. to 1.30 m d.b.h. for use in soft conversion of English volume to metric volume had to be developed.

METHODS

Fieldwork.—Data for this study came from a cooperative timber inventory conducted by the Forest Service and the State of Colorado in Grand County, Colorado. The inventory design systematically covered the county on a 5 000-m grid. Plots consisted of ten 40-basal area factor sampling points. Diameter of all sample trees was measured at 1.3 and 1.37 m above the ground line. Additional data were collected, but only diameter and height measurements were used for this study. Six species were represented: Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco), Engelmann spruce (*Picea engelmannii* Parry), lodgepole pine (*Pinus contorta*

Dougl.), subalpine fir (*Abies lasiocarpa* [Hook.] Nutt.), aspen (*Populus tremuloides* Michx.), and narrowleaf cottonwood (*Populus angustifolia* James).

Each species was considered separately for comparison of English with metric diameter measurements. Diameter measurements taken by the two standards differed by only a few tenths of an inch. Because volume prediction is the primary use of the diameter measurement, the diameter data were analyzed in terms of effect on volume prediction. A relative percent difference statistic was derived to make comparisons:

$$\text{VDIFF} = \frac{\text{MV}-\text{EV}}{\text{EV}} \times 100$$

where:

VDIFF = Percent volume difference between volumes computed with metric and English diameters.

MV = Volume computed with diameter measured at 1.3 m.

EV = Volume computed with diameter measured at 1.37 m.

Gross cubic-foot volume equations (to a 4-inch top) were used for cottonwood (Kemp 1958), Engelmann spruce (Myers and Edminster 1972), subalpine fir (Hatch 1975), Douglas-fir (Hatch 1975), aspen (Edminster and others 1981), and lodgepole pine (Myers 1972). All of these equations were developed using English standards with d.b.h. measured at 4.5 ft (1.37 m).

Statistics were analyzed by constructing 95 percent confidence limits on the volume difference statistic (VDIFF) sorted into groups by species and 2-inch diameter classes using both Student's t-test and the chi-square test. The chi-square confidence limits were derived using the pivotal quantity method (Mood and others 1974).

Student's t-test is commonly used in making paired comparisons, but Freese (1960) points out the chi-square test is more appropriate in most forestry applications. The chi-square test considers both bias and precision when making a paired comparison, while Student's t-test considers only bias. Both tests require normally distributed data. Figure 1 illustrates that this is a reasonable assumption for subalpine fir. The other species data had similar distributions. Table 1 lists the data with both Student's t-test and chi-square confidence limits. If a confidence limit does not include zero, there is a statistically significant difference between English and metric points of measurement. The confidence limits do not include zero for the most part. Those that do include zero are for a small sample size or for small trees that were not compatible with the volume percentage (VDIFF) transformation. Thus, these tests indicate that statistically the diameters taken at 1.3 m and 1.37 m are different, which is not unexpected. The question then becomes what impact will the diameters taken at the different measurement points have on volume?

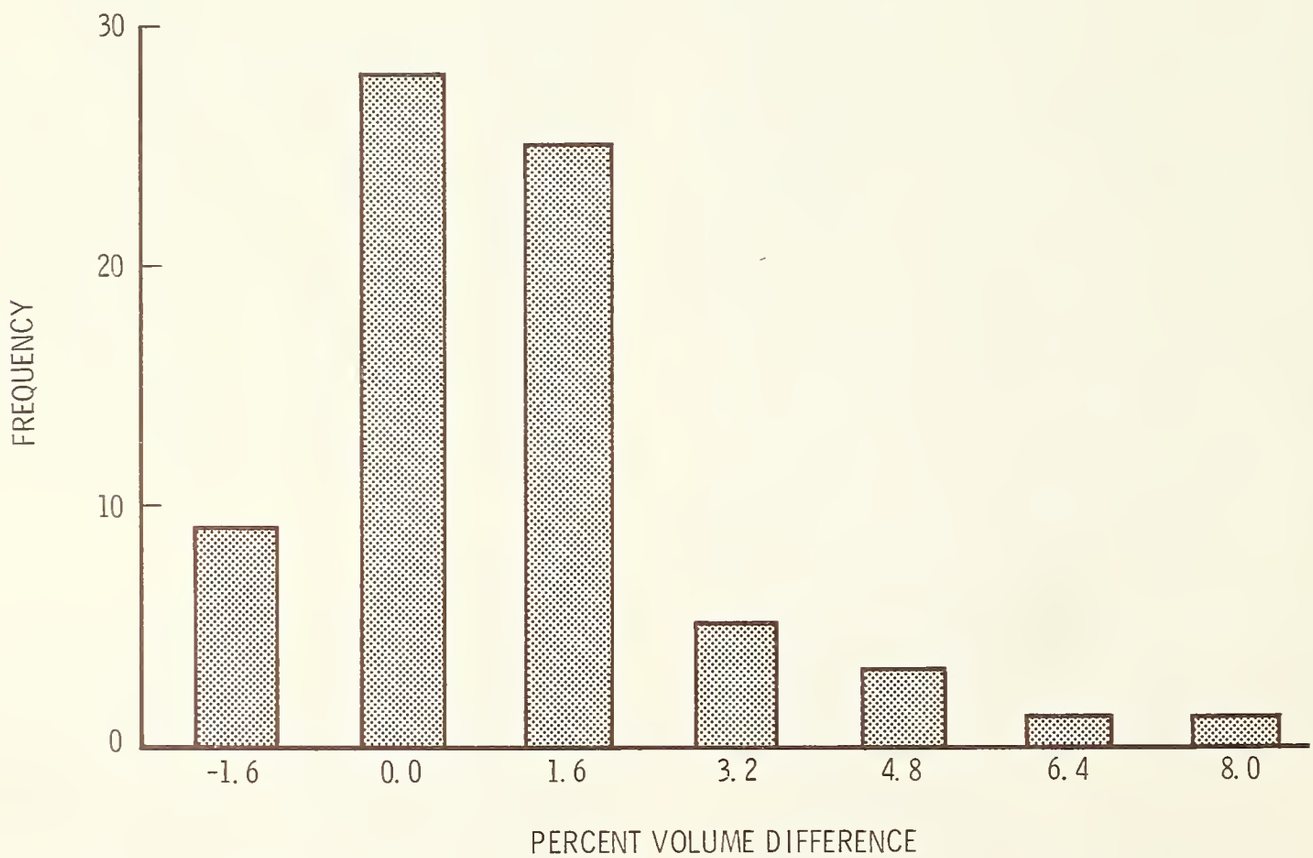

Figure 1.—Volume differences (VDIFF) for subalpine fir computed with metric and English diameters.

Table 1—Comparison of volumes (expressed as percentages) computed from diameters measured at 1.3 m (metric diameter) and 1.37 m (English diameter). Confidence limits (CL) are at the 95 percent level.

Diameter class	Number of trees	Mean diameter difference	Mean volume difference[1]	Median volume difference	Maximum volume difference	Minimum volume difference	Lower CL t-test	Upper CL t-test	Lower CL chi-square	Upper CL chi-square
					Subalpine fir					
5-6.9	34	.02	.7	1.3	5.6	-6.8	-.18	1.59	.58	.90*
7-8.9	33	.06	1.5	1.0	7.1	-3.1	.68	2.37*	1.39	1.74*
9-10.9	29	.01	.3	.7	6.6	-11.0	-.69	1.35	.18	.57*
11-12.9	21	.10	1.5	.6	8.8	-.7	.37	2.56*	1.27	1.83*
13-14.9	12	.07	1.0	.5	6.3	-1.0	-.36	2.27	.70	1.55*
15-16.9	8	.16	1.9	.9	4.6	.0	.31	3.42*	1.44	3.08*
17-18.9	3	.12	1.2	.8	2.0	.8	-.63	3.02	.70	4.32*
19-20.9	1	.24	2.2	2.2	2.2	2.2	.	.	.25	7.79*
21-22.9	1	-.12	-1.0	-1.0	-1.0	-1.0	.	.	-1.89	1.62
23-24.9	1	.16	1.2	1.2	1.2	1.2	.	.	.14	4.24*
Total	143	.05	1.0	.	.	.	.63	1.42*	.99	1.07*
					Lodgepole pine					
5-6.9	153	.03	1.4	0	16.6	-24	.66	2.09*	1.32	1.44*
7-8.9	219	.03	.9	1.0	12.5	-17	.47	1.25*	.83	.89*
9-10.9	254	.05	1.1	.8	14.5	-5.4	.80	1.34*	1.05	1.09*
11-12.9	155	.07	1.1	.7	9.7	-6.0	.73	1.46*	1.06	1.13*
13-14.9	118	.07	1.0	.5	9.1	-6.4	.56	1.37*	.93	1.01*
15-16.9	44	.06	.7	.7	8.5	-6.4	.11	1.37*	.66	.87*
17-18.9	19	.07	.8	.4	7.4	-1.7	-.12	1.69	.63	1.08*
19-20.9	6	.07	.7	.6	1.5	0	-.12	1.52	1.49	1.44*
Total	968	.05	1.0	.	.	.	.86	1.22*	1.03	1.05*
					Englemann spruce					
5-6.9	23	.05	2.0	1.7	22.2	-35	-2.35	6.45	1.37	3.26*
7-8.9	32	.05	1.6	1.1	9.4	-3.9	.46	2.68*	1.40	1.85*
9-10.9	28	.08	1.4	1.3	5.8	-3.3	.87	1.96*	1.33	1.54*
11-12.9	44	.08	1.4	1.3	5.8	-3.3	.87	1.96*	1.33	1.54*
13-14.9	29	.11	1.6	1.1	7.8	-.6	.87	2.26*	1.43	1.78*
15-16.9	42	.08	1.0	1.0	4.5	-3.5	.49	1.56*	.95	1.15*
17-18.9	24	.11	1.1	1.4	3.7	-.9	.69	1.61*	1.05	1.33*
19-20.9	19	.14	1.2	1.0	3.2	0	.75	1.58*	1.05	1.38*
21-22.9	5	.11	.9	.6	2.6	-0.3	-.48	2.28	.57	2.22*
23-24.9	3	.25	1.8	2.0	2.7	.8	-.45	4.11	1.10	6.44*
25-26.9	5	.28	2.0	1.9	3.1	1.3	1.16	2.84*	1.49	4.07*
27-28.9	2	.18	1.1	1.1	1.8	.5	-7.12	9.42	.47	5.38*
>29	4	.13	.8	.6	2.0	0	-.74	2.34	.46	2.48*
Total	260	.09	1.4	.	.	.	.99	1.86*	1.40	1.46*
					Cottonwood					
5-6.9	3	-.04	-1.4	-2.4	4.2	-5.9	-14.2	11.43	-3.00	8.96
7-8.9	3	.05	1.6	0	4.9	0	-5.38	8.64	.58	8.22*
9-10.9	2	-.04	-.9	-.9	-.8	-.9	-1.76	.01	-1.32	1.94
11-12.9	12	.05	.8	1.4	5.9	-4.0	-.85	2.47	.50	1.52*
13-14.9	8	.22	3.3	2.5	8.9	-2.3	-.08	6.59	2.44	5.61*
15-16.9	3	.10	1.4	1.6	2.6	0	-1.88	4.69	.75	5.55*
17-18.9	5	.10	1.1	1.3	3.5	-.5	-.94	3.17	.66	2.94*
19-20.9	7	.08	.8	1.3	2.1	1.2	-.31	1.97	.57	1.65*
21-22.9	1	.08	.7	.7	.7	.7	.	.	.09	2.65*
23-24.9	1	.04	.3	.3	.3	.3	.	.	.04	1.22*
25-26.9	1	-.28	-2.2	-2.2	-2.2	-2.2	.	.	-4.06	3.47
Total	46	.08	1.1	.	.	.	.24	1.91*	.97	1.23*

Table 1—(con.)

Diameter class	Number of trees	Mean diameter difference	Mean volume difference[1]	Median volume difference	Maximum volume difference	Minimum volume difference	Lower CL t-test	Upper CL t-test	Lower CL chi-square	Upper CL chi-square
Aspen										
5–6.9	104	.04	2.5	1.5	49.5	-29	.74	4.34*	2.38	2.74*
7–8.9	134	.02	.7	0	14.8	-9.8	.03	1.33*	.63	.75*
9–10.9	65	.05	1.1	.9	19.5	-25	-.24	2.41	.95	1.28*
11–12.9	31	.07	1.1	.7	11.2	-2.7	.11	2.14*	.97	1.37*
13–14.9	12	.11	1.4	1.3	3.9	-2.4	.27	2.46*	1.12	1.95*
15–16.9	2	.02	.2	.2	.5	0	-2.65	3.11	.06	1.26*
17–18.9	1	-.28	-3.0	-3.0	-3.0	-3.0	.	.	-5.57	4.76
Total	349	.04	1.4	.	.	.	.72	2.00*	1.33	1.40*
Douglas-fir										
5–6.9	4	.09	3.4	2.6	11.3	-2.8	-6.01	12.78	1.59	12.26*
7–8.9	2	0	.1	.1	3.0	-2.8	-37.04	37.56	-1.40	9.57
9–10.9	1	0	0	0	0	0	.	.	0	0
11–12.9	1	-.20	-3.1	-3.1	-3.1	-3.1	.	.	-5.77	4.93
13–14.9	2	.06	.8	.8	1.0	.5	-2.33	3.86	.35	3.34*
15–16.9	3	.10	1.1	.4	3.0	0	-2.83	5.09	.49	5.16*
17–18.9	2	.33	3.3	3.3	4.2	2.4	-7.63	14.23	1.56	14.25*
19–20.9	1	0	0	0	0	0	.	.	0	0
23–24.9	1	.47	3.6	3.6	3.6	3.6	.	.	.42	12.85*
Total	17	.10	1.5	.	.	.	-.23	3.26	1.20	2.14*

*The 95 percent confidence limit does not include zero. This means there is a statistically significant difference between volumes computed with English and metric diameter measurements.

[1]Mean volume difference $= \sum_{i=1}^{n} \frac{MV_i - EV_i}{EV_i} \times 100/n$ where: MV_i = volume in cubic feet computed with metric diameter. EV_i = volume in cubic feet computed with English diameter.

The average difference between metric and English diameters was mostly less than one-tenth inch, which corresponds to a little more than 1 percent bias. This positive bias is the expected result of using diameters measured at 1.3 m in volume equations developed for 1.37 m diameter measurements. The confidence limits indicate that the bias is most likely a population characteristic of about 1 to 2 percent.

Because most volume equations probably predict within 10 to 20 percent of the true value, a correction of 1 percent bias between metric and English measurements provides only a minor improvement in precision. Table 2 shows that a single correction for all species measured in Grand County, Colorado, is sufficient. The full and reduced model concept from Graybill (1976) was used to make this determination. The full

Table 2.—Results of testing six individual equations against the combined equation for predicting English d.b.h. from metric measurements

Source of variation	Degrees of freedom	Sum of squares	Mean square	F—value
Total	n = 1,783	221,188.6943		
Combined equation	p = 12	221,157.3758		
Individual equations	p - q = 2	221,157.2334		
Combined minus Individual	q = 10	.1424	0.01424	0.8054 ns[1]
Error variance	n - p = 1,771	31.3185	.01768	

[1]The .05 significance level is 1.83 for an F-value with 10 and 1,771 degrees of freedom. Hence, the hypothesis is accepted and each of the individual equations can be represented equally well by the combined equation.

model includes all species separately and the reduced model groups all species into one equation. The F-value is very small, indicating one correction equation is sufficient.

The equation is:

$$\text{Metric d.b.h.} = -0.0128 + 1.0065 \text{ English d.b.h.}$$

Sample size = 1,783 trees

A plot of the actual minus predicted values (residuals) is shown in figure 2.

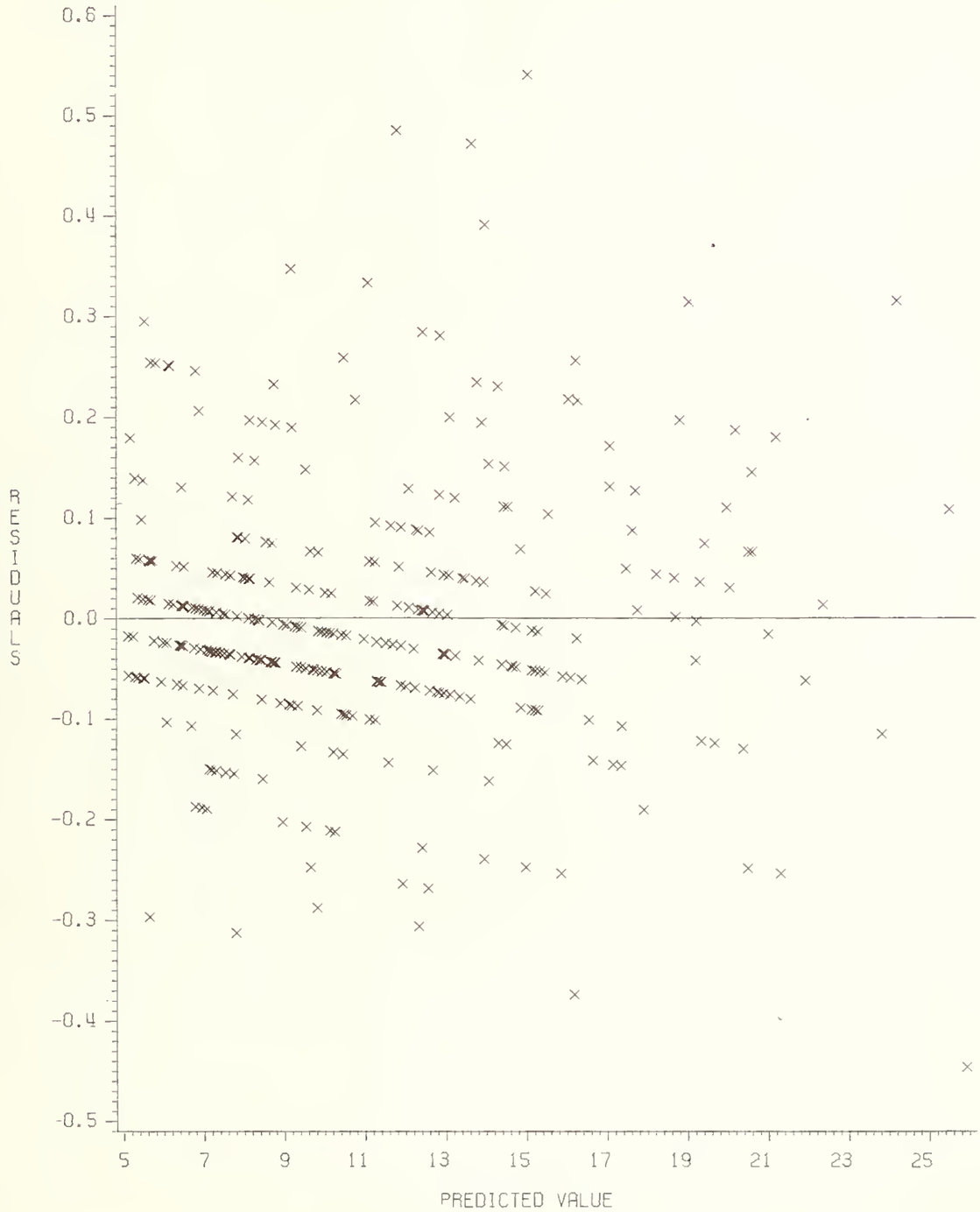

Figure 2.—A random subsample of residuals and predicted values for the model: metric d.b.h. = -0.0128 + 1.0065 English d.b.h.

DISCUSSION

The results of this study, while based on a rather restricted geographical sample, indicate that there is a small but statistically significant difference between diameter measurements taken at 1.37 m and those taken at 1.3 m. The correction factors developed for Grand County compare favorably with those presented by Bruce (1979) and Berry (1980). For example, assuming a 10.0-inch measurement taken at 4.5 ft (1.37 m), the formula developed by Bruce would yield a diameter of 10.05 at 1.3 m; Berry's correction would yield a diameter of 10.05 at 1.3 m, and the correction presented here would also yield 10.05. The implication is the equation presented here developed from Rocky Mountain species is functionally the same as those developed for naturally grown West Coast species and plantation-grown white spruce in Canada.

Since most volume equations are a function of diameter squared, it would follow that the next concern would be the impact of these diameter differences on volume. The relative difference (dash line in fig. 3) in volume estimates using diameter measured at 4.5 ft as opposed to 1.3 m is small. Generally, the largest relative difference is in the 6-inch-diameter class and continues to decline as diameter increases.

When this study was conducted, the trend in forest measurements in the United States was very much toward metric. Subsequent National policy, however, has deemphasized the adoption of the metric standard. Therefore, hard conversions to metric, in the near future at least, will probably not be required. Soft conversions, however, will still be required for comparative purposes in the international arena.

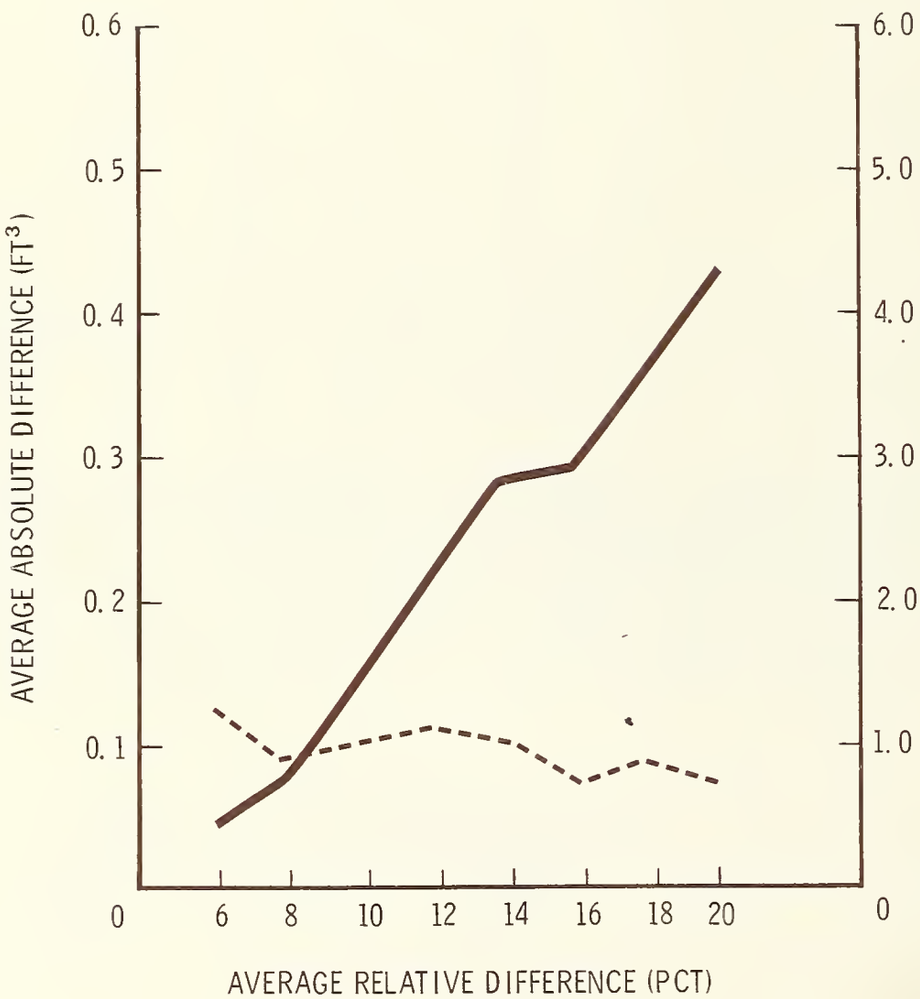

Figure 3.—Comparison of absolute (solid line) vs. relative (dashed line) differences in volume prediction using diameter measured at 4.5 ft vs. 1.3 m for lodgepole pine in Grand County, Colo.

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Van Hooser, Dwane D; Chojnacky, David C. Tree diameter measurements at English and metric standard heights: a comparison. Research Paper INT-327. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1984. 7 p.

Compares the difference between diameter and volume determination based on the English (4.5 ft, 1.37 m) versus the metric (1.3 m) diameter at breast height standard. Appropriate statistics are included and an equation for converting English to metric is presented.

KEYWORDS: volume, measurement, metric, diameter, diameter breast height

The Intermountain Station, headquartered in Ogden, Utah, is one of eight regional experiment stations charged with providing scientific knowledge to help resource managers meet human needs and protect forest and range ecosystems.

The Intermountain Station includes the States of Montana, Idaho, Utah, Nevada, and western Wyoming. About 231 million acres, or 85 percent, of the land area in the Station territory are classified as forest and rangeland. These lands include grasslands, deserts, shrublands, alpine areas, and well-stocked forests. They supply fiber for forest industries; minerals for energy and industrial development; and water for domestic and industrial consumption. They also provide recreation opportunities for millions of visitors each year.

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